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DOE/NASA/2817-2
NASA CR-165535
DOT/TSC/NASA-81-2

FUEL ECONOMY AND EXHAUST EMISSIONS CHARACTERISTICS OF DIESEL VEHICLES: TEST RESULTS OF A PROTOTYPE FIAT 131 TC 2.4-LITER AUTOMOBILE

S.S. Quayle

U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
Transportation Systems Center
Cambridge MA 02142

JANUARY 1982

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Cleveland OH 44135
Under Interagency Order C-32817-D

for
U.S. DEPARTMENT OF ENERGY
Conservation and Solar Energy
Office of Vehicle and Engine R&D
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PREFACE

This work was sponsored by the U.S. Department of Energy and managed by the NASA Lewis Research Center under Interagency Order C-32817-D. The author wishes to acknowledge the project support work of Mr. Robert Dezelick, Project Manager, NASA Lewis Research Center, and Mr. Maurice W. Dumais and Mr. Robert Walter of the Automotive Research Laboratory, Transportation Systems Center.

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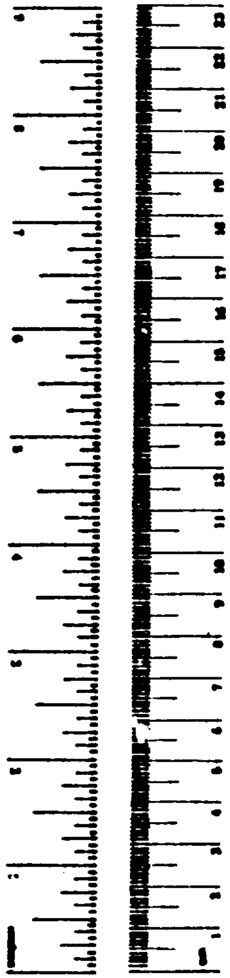
METRIC CONVERSION FACTORS

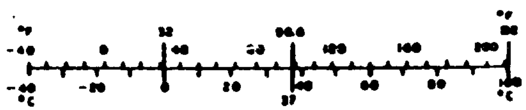
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

Under Interagency Order C-32817-D, the Department of Transportation, Transportation Systems Center (DOT/TSC) participates in a cooperative research program with the Department of Energy and NASA Lewis Research Center. The objectives of this project are two-fold:

1. To determine the ability of various diesel technologies to improve fuel efficiency and reduce exhaust emissions and,
2. To collect adequate particulate samples for chemical and biological characterization as part of the DOE Diesel Health Effects Research Program.

The vehicle used for the portion of the program discussed in this paper was a turbocharged (TC) Fiat prototype diesel. This vehicle was loaned to TSC by Fiat through contract DOT-TSC-1424. The Fiat 131 TC (rated 85 hp at 4000 rpm) was tested at the DOT/TSC Automotive Research Laboratory in a 3000-lb inertia weight configuration (Figure 1) following the matrix employed to test the Fiat 131 naturally aspirated vehicle. Both cars were equipped with 2.4 liter indirect injection engines and five-speed manual transmissions. Both were tested over selected drive cycles and steady-state conditions on a large-roll, chassis dynamometer. Test cycles consisted of the EPA/Federal Test Procedure Urban Cycle (FTP), the Highway Fuel Economy Test (HFET), the Congested Urban Expressway Cycle (CUE), and the New York City Cycle (NYCC). Steady-state measurements were collected at five different speed-gear combinations. Approximately 11 grams of particulate matter were collected and sent to Lovelace Inhalation Toxicology Research Institute for use in the DOE Diesel Health Effects Research Program. (See Table A-1 in Appendix.)

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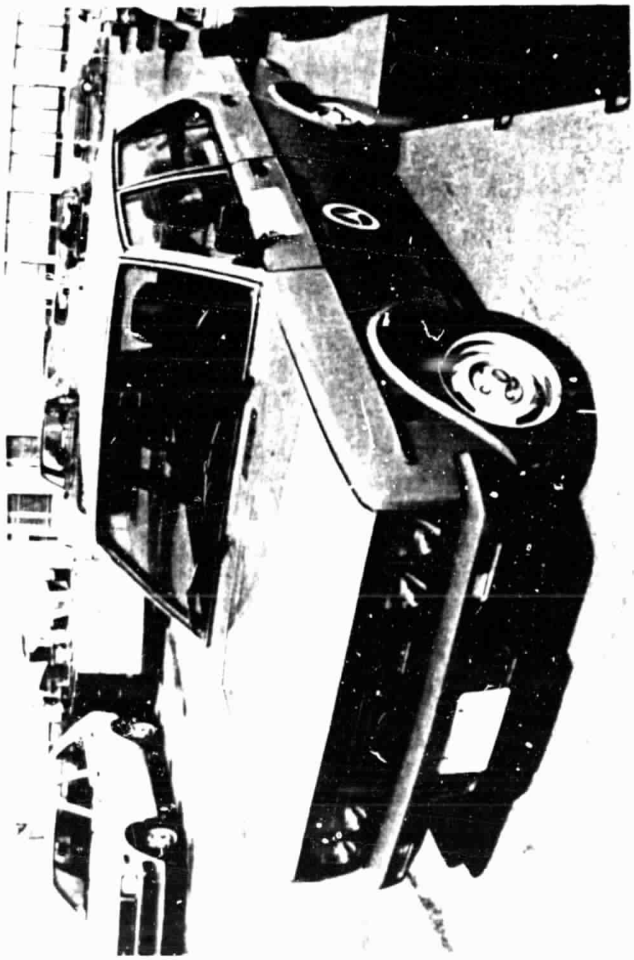

FIGURE 1. FIAT 131 TC DIESEL IN A 3000 LB INERTIA VEHICLE

2. EXPERIMENTAL DESIGN

2.1 TEST VEHICLE

This section describes the salient features of the Fiat 131, TC. For a more detailed description of the prototype vehicles both NA and TC and test procedures, refer to Fuel Economy and Exhaust Emissions Characteristics of Diesel Vehicles: Test Results of a Protoype Fiat 131 NA 2.4-Liter Automobile[1] and the Fiat manufacturer's report.[2]

2.1.1 Engine and Vehicle Specifications

The engine, a 2.4-liter prototype indirect injection diesel rated at 85 hp at 4000 rpm, is one of the Fiat Sofim family of 3, 4, and 6 cylinder engines. The main specifications of the turbocharged and the naturally aspirated Fiat engines are given in Table 1.

The vehicle's inertia weight is 3000 pounds. Its frontal area is 1.83 m^2. Tire size is 185/70-13. The Fiat 131 TC vehicle is equipped with a five speed manual transmission with gear ratios of 3.85, 2.528, 1.448, 1.0 and 0.757; the axle ratio is 3.583.

2.1.2 Manufacturer's Data on Emissions, Fuel Economy, and Performance

The 0-60 mph acceleration of the TC as determined by the manufacturer is 14.1 seconds compared to 18.1 seconds for the NA vehicle. The turbocharged vehicle has a higher rear axle ratio, 3.58 compared to 3.20. The emissions rates as determined by the manufacturer are as follows: 0.33/1.3/1.45/0.32 grams per mile of HC/CO/NO_x/particulates, respectively. The manufacturer-determined FTP Urban Cycle fuel economy number is 31 mpg.

2.1.3 Fuel

Two fuels were used in the test series. One fuel was provided by the Environmental Protection Agency and is hereafter cited

TABLE 1. FIAT 131, 4-CYLINDER, INDIRECT INJECTION IN-LINE

	TURBOCHARGED	NATURALLY ASPIRATED
BORE	93 mm	93 mm
STROKE	90 mm	90 mm
STROKE/BORE	0.97	0.97
TOTAL DISPLACEMENT	2445 cm^3	2445 cm^3
COMPRESSION	22:1	22:1
MAXIMUM POWER @ RATED SPEED	85 hp @ 4000 rpm	70 hp @ 4200 rpm
FUEL INJECTION PUMP	ROTARY BOSCH VE 4/10	ROTARY BOSCH VE 4/9
PLUNGER DIAMETER	10 mm	9 mm
STATIC INJECTION TIMING (at 1mm plunger lift)	3° C.A. ATDC	1° C.A. BTDC
GEAR RATIOS	3.850, 2.528, 1.448, 1.00, 0.757	3.612, 2.045, 1.357, 1.00, 0.870
REAR AXLE RATIO	3.58	3.20
TURBOCHARGER	Garrett 7992 T3 with waste gate calibrated at 0.7 bar.	

as EPA fuel; the other fuel was provided by Fiat and is hereafter cited as European (or Eur) fuel. The fuel analyses are given in Table 2.

The EPA fuel was taken from a common lot that has been used in other test vehicles to generate particulate samples for the EPA Diesel Health Effects Research Program. It has a high specific gravity and relatively low cetane index; this consequently tends to slightly increase the specific fuel consumption (g/hp-hr). The Environmental Protection Agency/Research Triangle Park reports that the fuel has a mid-range aromatic content tending to increase smoke emissions and lower the cetane index. The sulfur content of the EPA fuel (0.25%) is typical of an ASTM Grade 2-D fuel. In contrast, the European diesel fuel has both a higher cetane index and higher sulfur content (0.77%).

2.2 TEST EQUIPMENT

This section briefly describes the test equipment and the gaseous and particulate measurement techniques.

2.2.1 Dynamometer

The DOT/TSC chassis dynamometer is a fully programmable direct-current machine with a single 50-inch diameter roll. The features of this dynamometer are shown in Table 3. This dynamometer can simulate, individually and in combination, loads due to rolling losses, aerodynamic drag, vehicle inertia, uphill and downhill grades, as well as road speed air-flow. Test cell temperature is normally controlled at $77^{\circ} \pm 5^{\circ}$F. Vehicle inertia can be simulated electrically or mechanically via flywheels. For the tests conducted on the prototype Fiats, electrical simulation of inertia was used.

Coast-down data was supplied by Fiat. The experimentally derived settings for the prototype Fiats were empirically modified to duplicate the manufacturer's. The dynamometer settings and coast-down curve for the Fiat vehicles are given in Figure 2.

TABLE 2. DIESEL FUEL CHARACTERISTICS*

	EPA/RTP #2 Diesel	European Diesel	Test Method
Hydrogen Ratio	1.79	1.92	Calculation based on atomic weight
Specific Gravity	0.849	0.836	ASTM D1298-67.
BTU/lb	19,541	19,572	ASTM 240-76.
BTU/gallon	138,116	135,888	ASTM 240-76.
Hydrogen, %	13.03	13.64	Pregl modified Ingram technique
Carbon, %	86.75	84.68	Pregl modified Ingram technique
Sulfur, %	0.25	0.77	ASTM D15522-64.
Cetane Index	48.5	56.5	ASTM 0976-66.
Distillation Range°F			ASTM D86.
IBP	387	371	
10%	430	423	
50%	509	520	
90%	599	631	
End Point	652	689	
Recovery, %	98.5	99.0	

*Analyses performed by Skinner and Sherman, Inc., New England Laboratories, Waltham, Massachusetts.

TABLE 3. DIRECT CURRENT CHASSIS DYNAMOMETER

- SINGLE AXIS, LARGE (50-INCH DIAMETER) ROLL (400 REVOLUTIONS/MILE)
- MAXIMUM TORQUE, SPEED: 6400 LB-FT, 0-39 MPH
- MAXIMUM POWER, SPEED: 315 HP, 39-105 MPH
- TORQUE SENSITIVITY: ±1.3 LB-FT (0.02% FULL SCALE)
- CORRESPONDING TRACTIVE FORCE AT WHEELS: ±0.61 LB
- DUAL TORQUE LOAD CELLS, 150% AND 15% OF FULL SCALE
- SIMULATED ROAD-SPEED AIR FLOW: 0-72 MPH
- MAXIMUM DRIVE-AXLE LOAD CAPACITY: 5000 LB
- MECHANICAL INERTIA OF SYSTEM EQUIVALENT TO VEHICLE WEIGHT OF 1800 LB
- ELECTRICAL SIMULATION OF VEHICLE WEIGHT FROM 1200 LB TO 7000 LB
- MECHANICAL SIMULATION OF VEHICLE WEIGHT FROM 1800 LB TO 8750 LB
- DIGITAL TORQUE CONTROL SYSTEM, PROGRAMMABLE TO SIMULATE:
  - ROLLING AND AERODYNAMIC LOSSES
  - VEHICLE INERTIA
  - POSITIVE AND NEGATIVE GRADES
  - HEAD AND TAIL WINDS
- ADJUSTABLE CONSTANT-SPEED CONTROL
- FULL DRIVE-CYCLE CAPABILITY

Dynamometer Settings

Speed Independent	- 7000 newton/kg
Speed Dependent	- 1000 newton/kg/km/hr
Windage	- 0.0418 (newton/km/hr)^2
Vehicle Weight	- 1361 kg
System Mech. Wt.	- 825 evw/kg
Manual Torque	- 0
Grade	- 0%

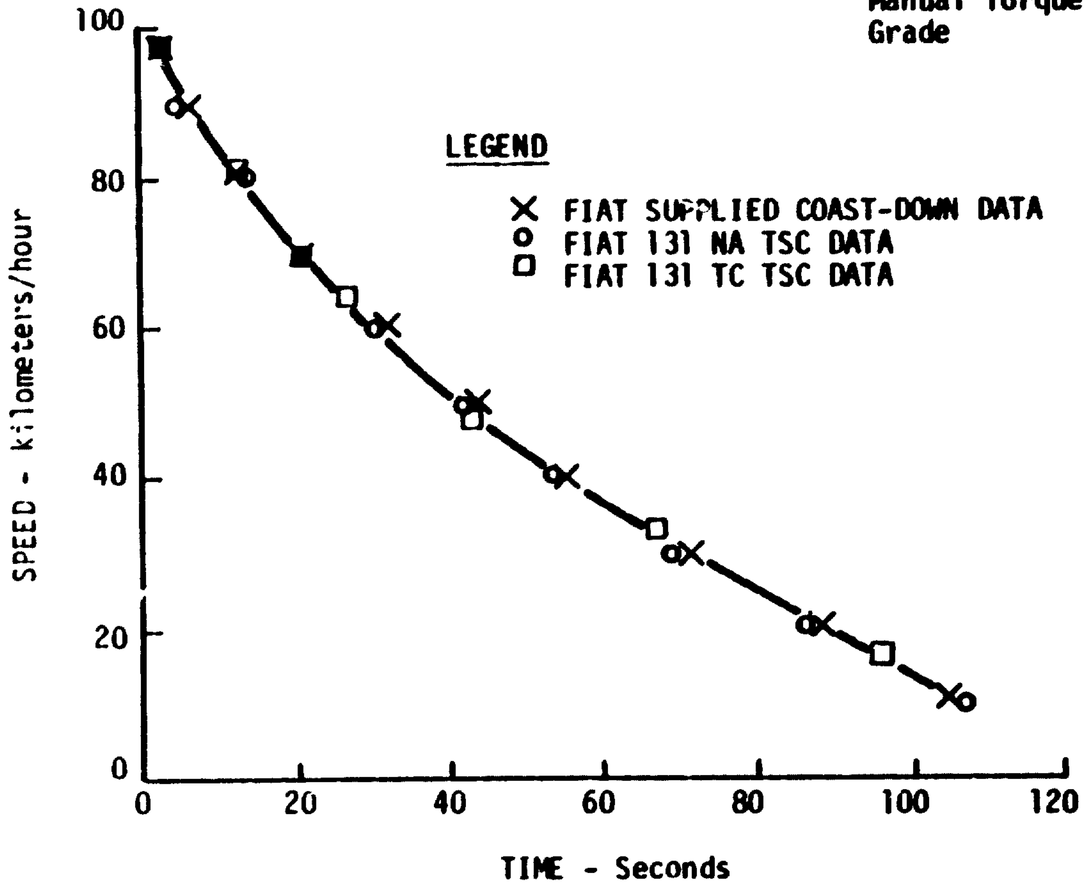

FIGURE 2. COAST-DOWN CHARACTERISTICS OF FIAT 131

2.2.2 Gaseous Emission Measurements

All measurements of gaseous hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x), and carbon dioxide (CO_2), were performed using a 325 cfm Constant Volume Sampling (CVS), with a Critical Flow Orifice (CFO) (Figure 3). For all tests, the gas samples (except HC) were collected in Tedlar bags. The instrumentation and procedures employed are those designated by EPA.[3] The instrumentation included non-dispersive infrared (NDIR) analyzers for CO and CO_2, a chemiluminescence analyzer with converter for NO_x, and a heated flame ionization detector (FID) for hydrocarbons (Table 4). For further detail regarding test procedures and instrumentation please refer to the Fiat 131 NA Report.[4]

2.2.3 Particulate Emission Measurement

Particulate mass measurements were performed using a dilution tunnel and the EPA recommended procedures for light-duty diesel vehicles.[5] The 8-inch diameter tunnel and its associated hardware are shown schematically in Figure 3. Tunnel specifications are listed in Table 5; particulate sampling instrumentation is indicated in Table 6.

To determine particulate mass (grams per mile), a sample of the diluted exhaust was extracted from the bulk-stream tunnel flow at a point which was 11 tunnel diameters downstream of the vehicle exhaust injection. The particulate sample probes (two each) were 1-inch diameter stainless-steel. The filter medium used was a 47-mm Pallflex T60A20 Teflon-coated fiberglass element held in Millipore model I quick-release holders.

For the substantial amounts of particulate matter needed for the EPA Diesel Health Effects Research Study, 20-inch x 20-inch Pallflex type T60A20 filters were used. These filters were mounted in parallel in two filter holders (Figure 4) that sampled approximately 25% of the exhaust stream after the dilution tunnel. All

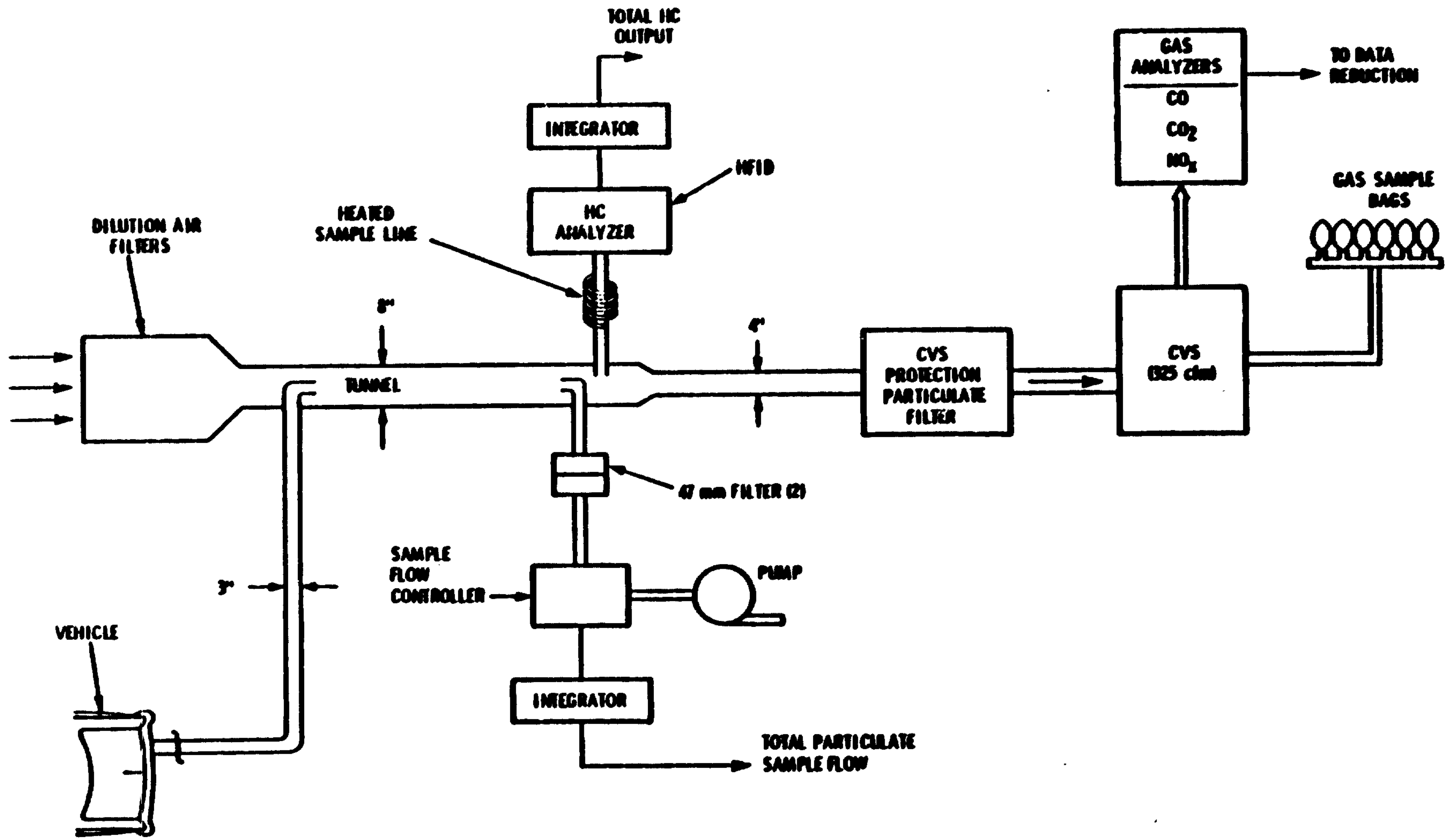

FIGURE 3. AUTOMOTIVE RESEARCH LABORATORY PARTICULATE/ GAS SAMPLING SYSTEM (CHARACTERIZATION)

TABLE 4. GASEOUS EXHAUST EMISSION INSTRUMENTATION

Exhaust Species	Method	Model Number
Hydrocarbon	Heated Flame Ionization Detector	Scott 215 Beckman 402
Carbon Monoxide	Non-Dispersive Infrared (NDIR)	Horiba AIA-21 (AS) low range MSA 202 high range
Nitrogen Oxides	Chemiluminescence with Thermal Converter	Scott 125
Carbon Dioxide	NDIR	MSA 202
Oxygen	Paramagnetic	Beckman

Calibration Gases: ± 2% National Bureau of Standards Traceable.

TABLE 5. EXHAUST DILUTION TUNNEL SPECIFICATIONS

Diameter	8 inches
Minimum Active Length*	75 inches
Minimum Residence Time	0.42 sec. @325 cfm
Material	Stainless Steel
Air Filters	
Prefilter	Cambridge Model 3CP60
Hydrocarbon Filter	Cambridge Activated Carbon Model 5FB45
Absolute Filter	Cambridge Model 1B-1000-1
Connecting Tubing - vehicle to tunnel	3-inch stainless steel smooth wall and silastic flexible couplings
Connecting Tubing - tunnel to CVS	4-inch flexible stainless steel and marmon couplings

*Distance From Vehicle Exhaust Exit To Nearest Sampling Port.

TABLE 6. EXHAUST PARTICULATE SAMPLING AND MEASUREMENT

Characterization	
Sample Probes	1 in. diam. stainless steel
Filter Holder	Millipore 47 mm
Filter Medium	Pallflex T60A20 Fluoropore
Sample Flow Control	Tylan Mass Flow Controller Model FC202 and FMT-3 electronics unit Model FMT-3 Integrator
Scale	Cahn Electrobalance, Model G
Large Volume Collection	
Filter Media	Pallflex T60A20 20" x 20"
Sample Flow Control	PDP pumped sample of approx. 100 cfm
Scale	Mettler P1200 (Modified)

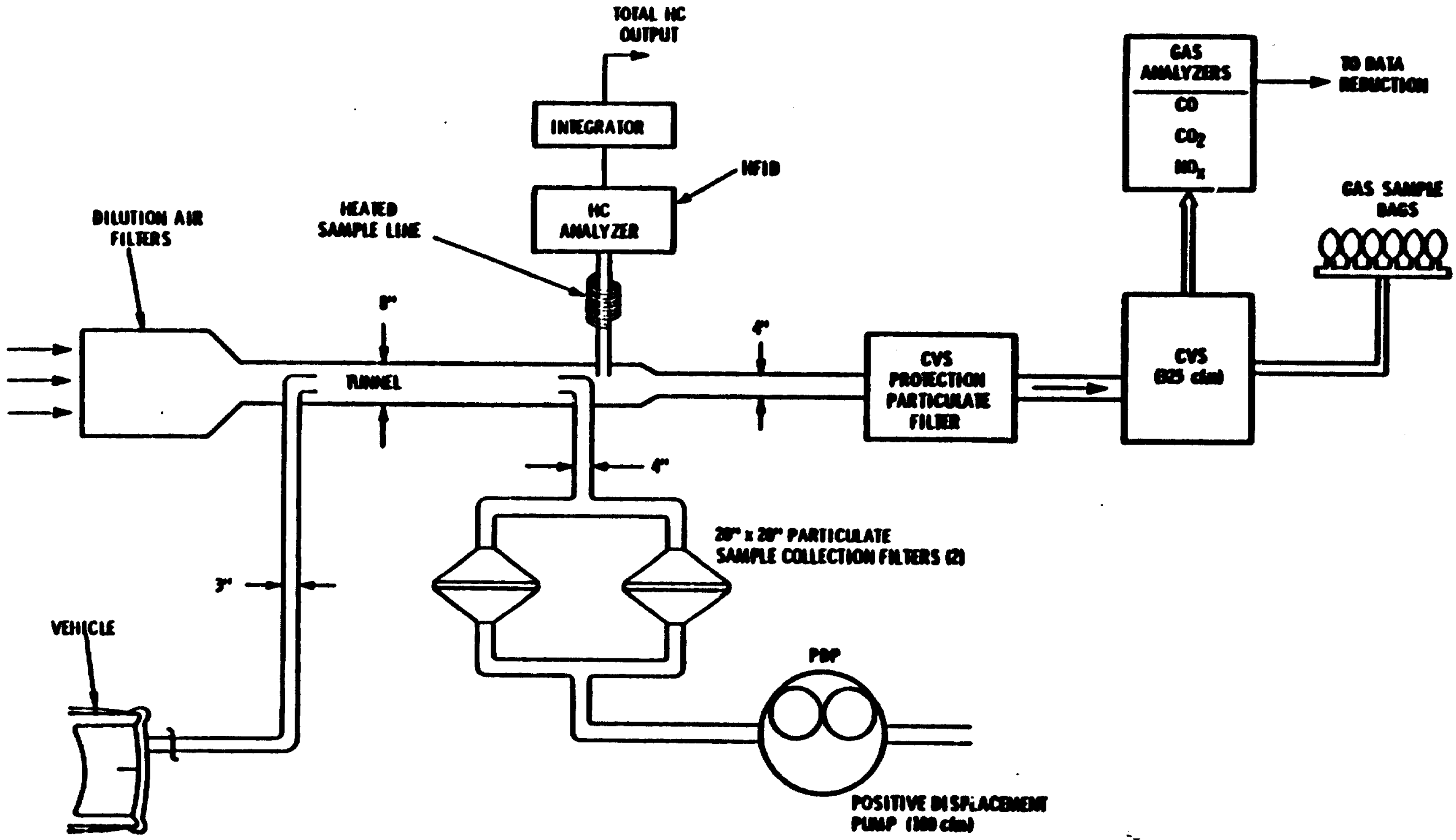

FIGURE 4. AUTOMOTIVE RESEARCH LABORATORY PARTICULATE/GAS SAMPLING SYSTEM (LARGE SCALE PARTICULATE COLLECTION)

large and small filters were stored in a temperature and humidity controlled room prior to sample collection. After collections, the filters were allowed to stabilize in the weigh room prior to reweighing. After weighing, filters were placed in Tedlar envelopes and placed in dark freezer storage (approximately -20°C) as is recommended by EPA/RTP.

3. TEST PROCEDURES

The laboratory test procedures used for determining the gaseous and particulate emissions rates and the fuel economy of the Fiat 131 TC are those described in the Code of Federal Regulations. For further detail refer to the Code or the Fiat 131 NA Report. As with the NA Fiat, two types of tests were conducted:

- o Characterization tests from which the gaseous and particulate exhaust emission rates and fuel economy were determined and
- o Large-volume sampling tests during which large amounts of diesel exhaust particulates were collected on 20-inch x 20-inch filters for chemical and biological analyses.

The characterization tests employed the Federal Test Procedure Urban Cycle (FTP), the Highway Fuel Economy Test (HFET), the Congested Urban Expressway (CUE) Cycle and the New York City Cycle (NYCC) in addition to the steady-state speeds of 15 mph in second gear, 25 mph in third gear, 40 mph in fourth gear and 50 and 60 mph in fifth gear. The large-volume sampling test involved only the cyclic tests. Table 7 summarizes the characteristics of the four transient test cycles. Shift points were made according to the manufacturer's recommendations:

2nd to 3rd gear....@	15 mph
3rd to 4th gear....@	25 mph
4th to 5th gear....@	40 mph

Cyclic tests were driven as though no first gear existed.

TABLE 7. DRIVE CYCLE CHARACTERISTICS

Cycle	Distance (miles)	Avg. Speed (mph)	Time (sec)	Remarks
Federal Test Procedure (FTP)	11.1	21.6	1877	Composite
- Bag 1	3.6	25.6	505	Cold Start
- Bag 2	3.9	16.2	867	Stabilized
- Bag 3	3.6	25.6	505	Hot Start
Highway Fuel Economy Test (HFET)	10.2	48.2	765	
Congested Urban Expressway - Sulfate (CUE)	13.3	34.2	1398	
New York City Cycle (NYCC)	1.1	6.6	598	

4. RESULTS

The Fiat 131 TC vehicle tests included four cyclic tests and five steady-state conditions as previously detailed in Section 3. At least three identical runs were conducted for each test point. Data for each of the cyclic tests and 5 steady-state points were collected for the vehicle run on EPA fuel. When the vehicle was run on European fuel, tests were limited to the FTP Urban and Highway cycles. The numerical results (including means and standard deviations) are included in the appendix (Tables A-2-14).

OVERALL RESULTS

The turbocharged Fiat exhibited good overall performance and operability. Generally, the fuel economy was higher; the hydrocarbon, carbon monoxide, and particulate emission rates lower; and the performance better than the naturally aspirated version. The oxides of nitrogen levels were generally equal, and sometimes better than the NA levels. The increased operating temperatures in the turbocharged vehicle were successfully offset by the TC vehicle's retarded injection timing. The turbocharged vehicle's urban fuel economy (33.2 mpg)(Fig. 15) was considerably better than the naturally aspirated vehicle's fuel economy (27.4 mpg) when both vehicles were run on European fuel. The TC vehicle's better fuel economy was, in part, due to its different drive-train/engine match.

The TC Fiat appeared to be more fuel sensitive than the NA vehicle and exhibited a significantly lower urban fuel economy (27%) when run on EPA fuel.

The prototype vehicle was able to meet the 1982 Federal emission standards of 0.41/3.4/1.5*/0.6 g/mi of HC/CO/NO_x/particulate respectively (Figures 5 and 6). When run on EPA fuel, the emission rates were 0.30/1.38/1.23/0.31 g/mi respectively. When

*The Federal NO_x emission limit is currently set at 1.0 g/mi. However, a waiver extending the limit to 1.5 g/mi is available through MY83.

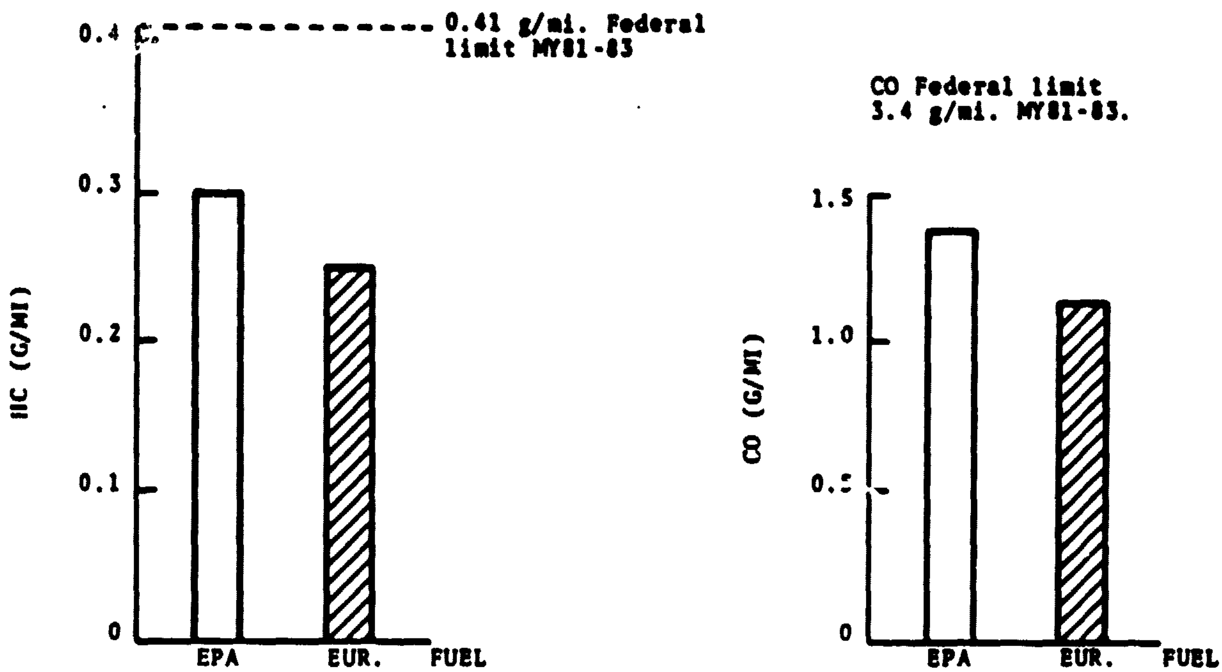

FIGURE 5. EMISSIONS OF FIAT 131 TC DIESEL, URBAN FEDERAL TEST PROCEDURE

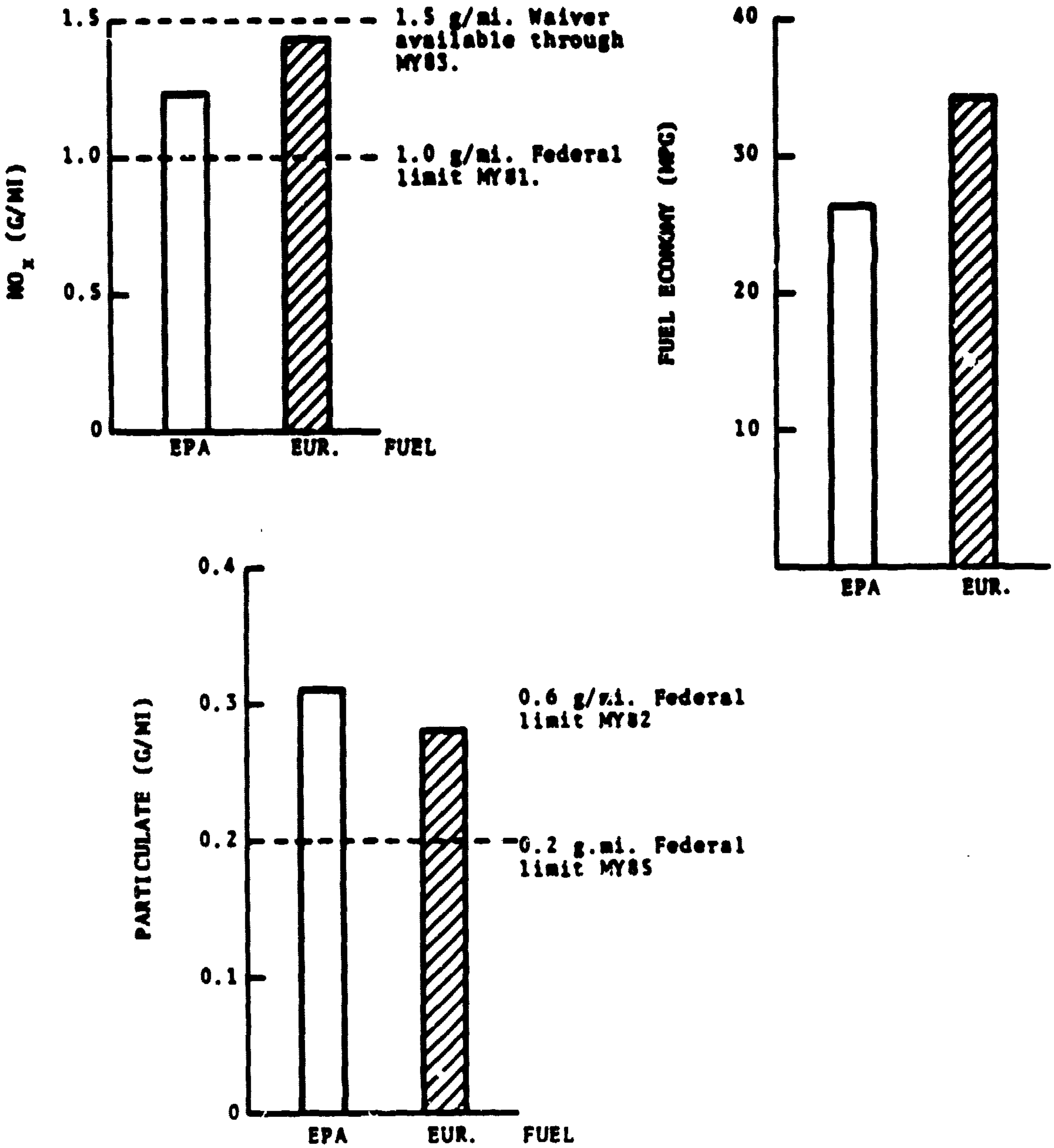

FIGURE 6. EMISSIONS AND FUEL ECONOMY OF FIAT 131 TC DIESEL, URBAN FEDERAL TEST PROCEDURE

run on European fuel, the emissions were 0.25/1.14/1.43/0.28 g/mi of HC/CO/NO_x/particulates respectively; all measured emissions improved with the higher cetane European fuel, except NO_x.

The highway fuel economy and emission trends were similar to those of the FTP urban results.

Hydrocarbon

As is evident from Figures 7 and 8, hydrocarbon emission levels are dependent on fuel type and operating temperature. Both of the EPA fueled Fiat prototypes had higher HC emissions (11 to 30% for the Urban and Highway cycles) than the vehicles run on European fuel. This can be attributed substantially to two factors. The EPA fuel had a lower cetane number than the European fuel, 48.5 and 56.5 respectively. Secondly, the vehicle was optimized for European fuel; no engine or component changes were made between fuels. The two vehicles appeared to be equally fuel sensitive with respect to HC emissions.

In both the cyclic and steady state tests, the hydrocarbon emissions were consistantly lower in the TC vehicle. Hydrocarbon levels for the FTP urban cycle were reduced to 0.25 and 0.30 g/mi (European fuel and EPA fuel, respectively) or an average reduction of 8%. Highway cycle levels were lowered to 0.07 and 0.10 g/mi (European and EPA fuel respectively) or an average reduction of 71%. Turbocharging increases the average gas temperature, and thus increases the rate of oxidation. Unburned hydrocarbons are consequently reduced, a process which is enhanced by further oxidation reactions in the exhaust manifold and the turbocharger.

It should also be noted that the static injection timing (SIT) (at 1 mm plunger lift) of the turbocharged and naturally aspirated vehicles respectively were 3° crank angle after top dead center and 1° crank angle before top dead center. Retarding the SIT of an NA vehicle would normally tend to increase HC emissions although for the TC vehicle a net decrease was noted. With the SIT retardation over the six steady state tests performed, HC levels were reduced an average 61% due to turbocharging (Figure 7). The greatest percentage reduction was at the 60 mph point.

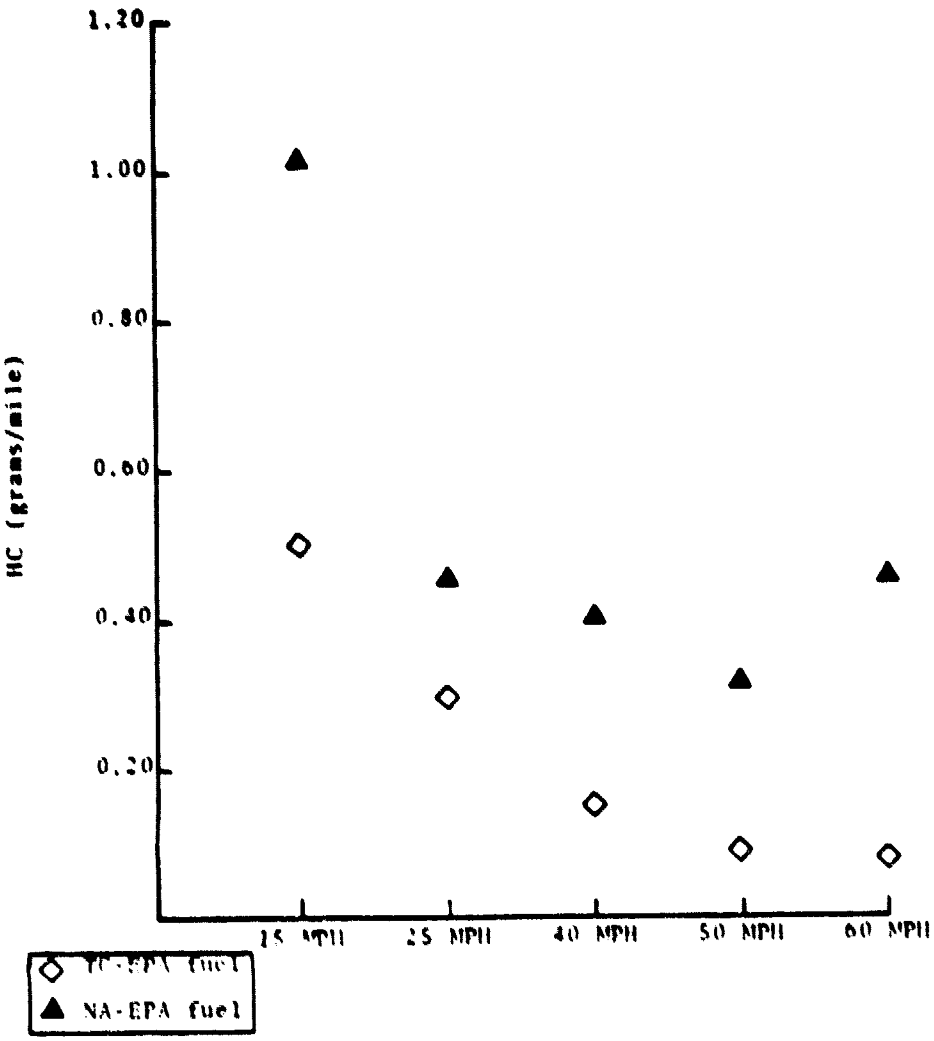

FIGURE 7. FIAT PROTOTYPES: TURBOCHARGED (TC) AND NATURALLY ASPIRATED (NA) 131 <u>HC EMISSIONS</u> - STEADY STATE

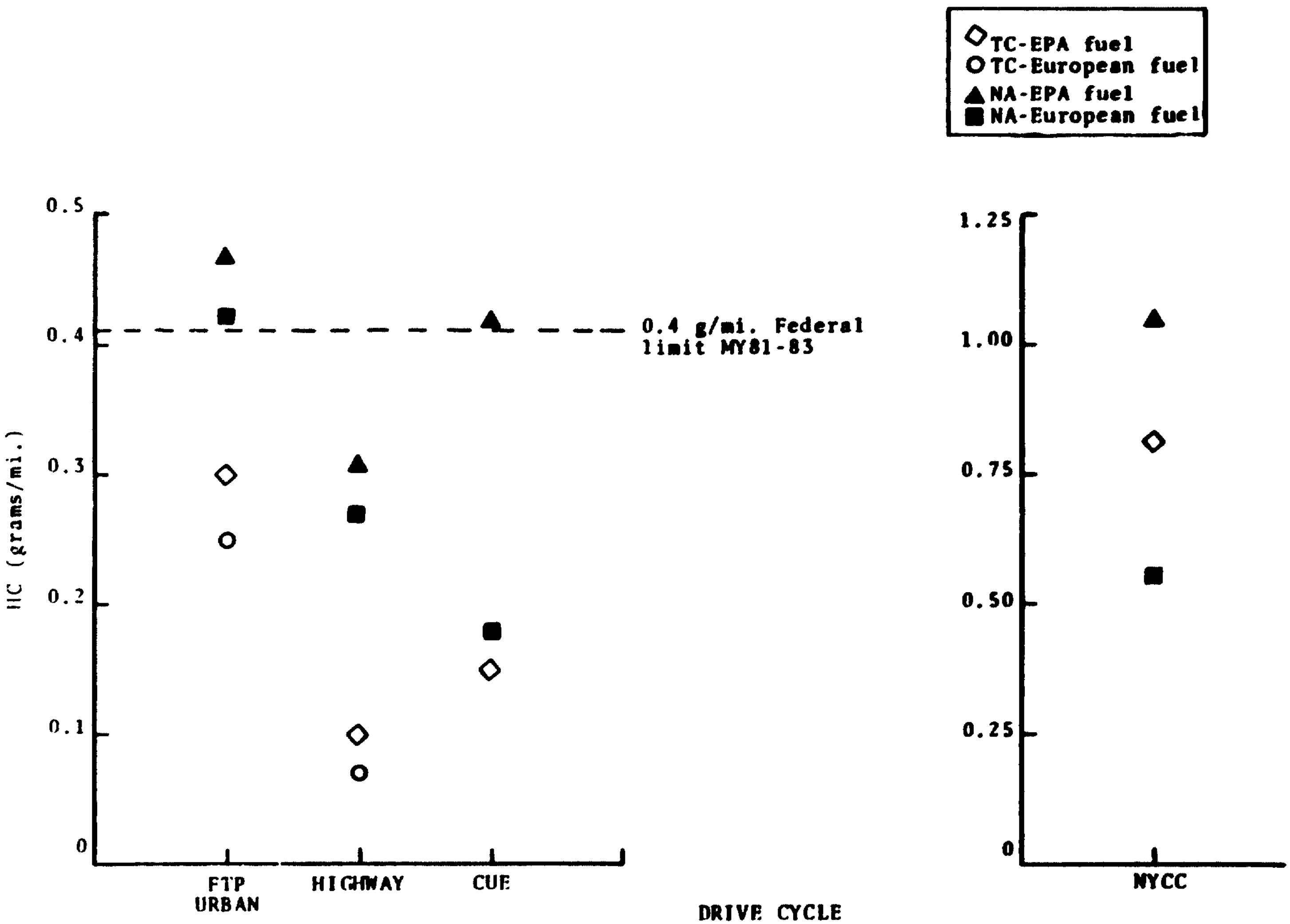

FIGURE 8. FIAT PROTOTYPES: TURBOCHARGED (TC) AND NATURALLY ASPIRATED (NA) 131 HC EMISSIONS - CYCLIC TESTS

Carbon Monoxide

Carbon monoxide emissions were likewise affected by fuel type and the use of turbocharging. The amount of CO emitted from the Fiat prototypes appeared to be less dependent on fuel type than were the HC levels. The CO emission levels from the turbocharged vehicle were adversely affected by the EPA fuel to a limited extent: 1.38 and 0.48 g/mi over the Urban and Highway cycles respectively from 1.14 and 0.45 g/mi respectively for the European-fuel vehicle (Figure 9). The use of turbocharging, however, did reduce CO emissions significantly: for the FTP Urban Cycle (EPA fuel), 22%; for the Highway Cycle (EPA fuel), 35%; and for the steady states tests (average of six configurations, EPA fuel), 26%. (Figure 10)

Oxides of Nitrogen

Nitrogen oxide levels, like CO and HC levels, depend on operating temperatures and fuel characteristics. In addition, NO_x production depends on the drive train match, rear axle ratio and static injection timing.

The turbocharged vehicle's NO_x levels appeared to be significantly affected by fuel properties. However, the change in levels relative to fuel showed little correlation with several previous studies which found NO_x inversely proportional to fuel's cetane number;[6] in fact the reverse trend appeared (Figure 11). (In the case of the naturally aspirated vehicle tested over the FTP Urban, Highway, CUE, and New York City cycles, NO_x levels were consistantly higher when the vehicle was run on the lower cetane EPA fuel.)

Some investigators have also found a direct relationship between aromatic content and NO_x formation.[7] The EPA fuel did have a higher aromatic content than the European fuel and the European-fueled vehicle did have lower NO_x emissions.

It is difficult to determine how the NO_x levels were affected by turbocharging due to the limited test matrix. Turbocharging causes increased system temperatures, thus tending to increase NO_x

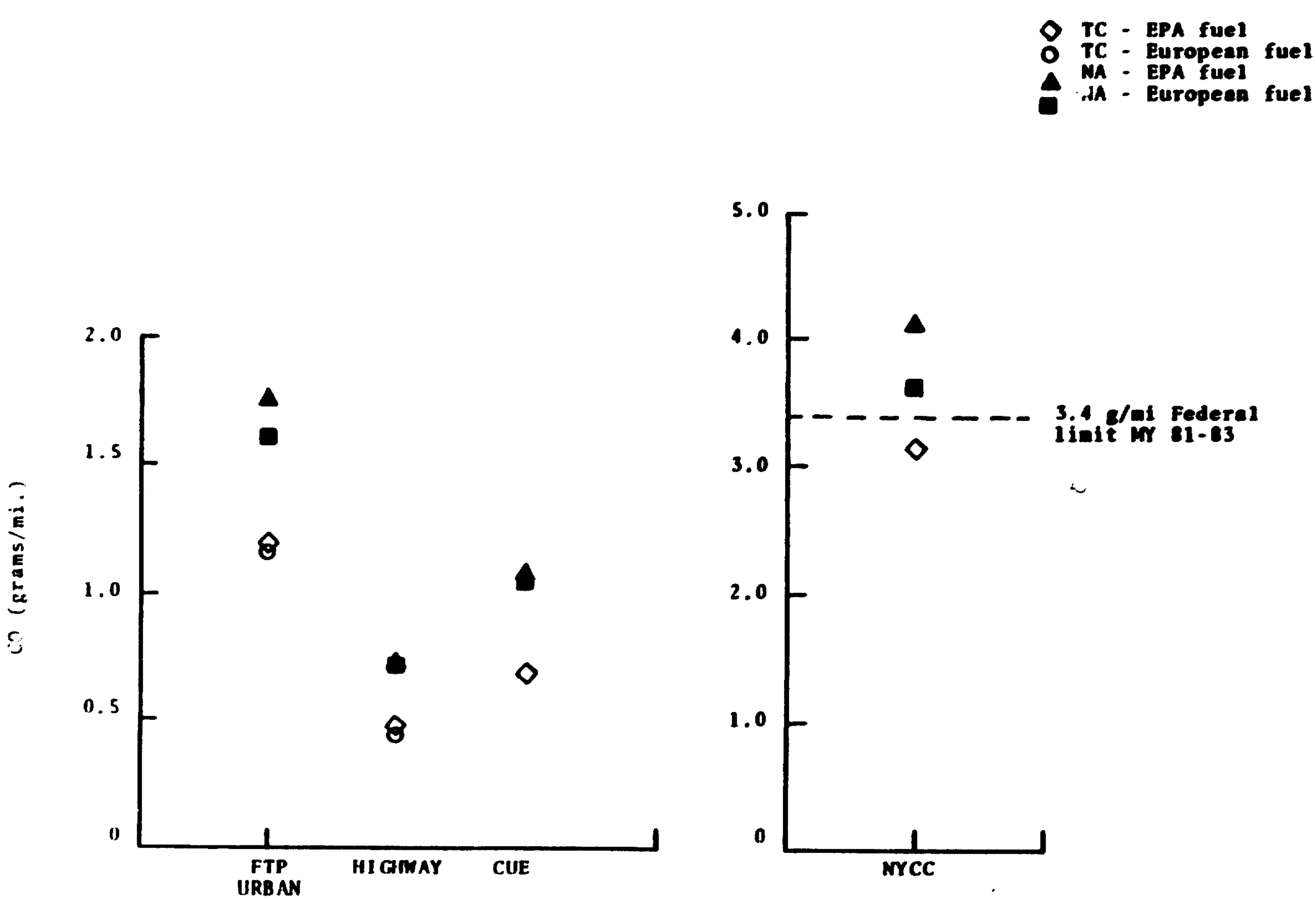

FIGURE 9. FIAT PROTOTYPES: TURBOCHARGED (TC) AND NATURALLY ASPIRATED (NA) 131 CO EMISSIONS - CYCLIC TESTS

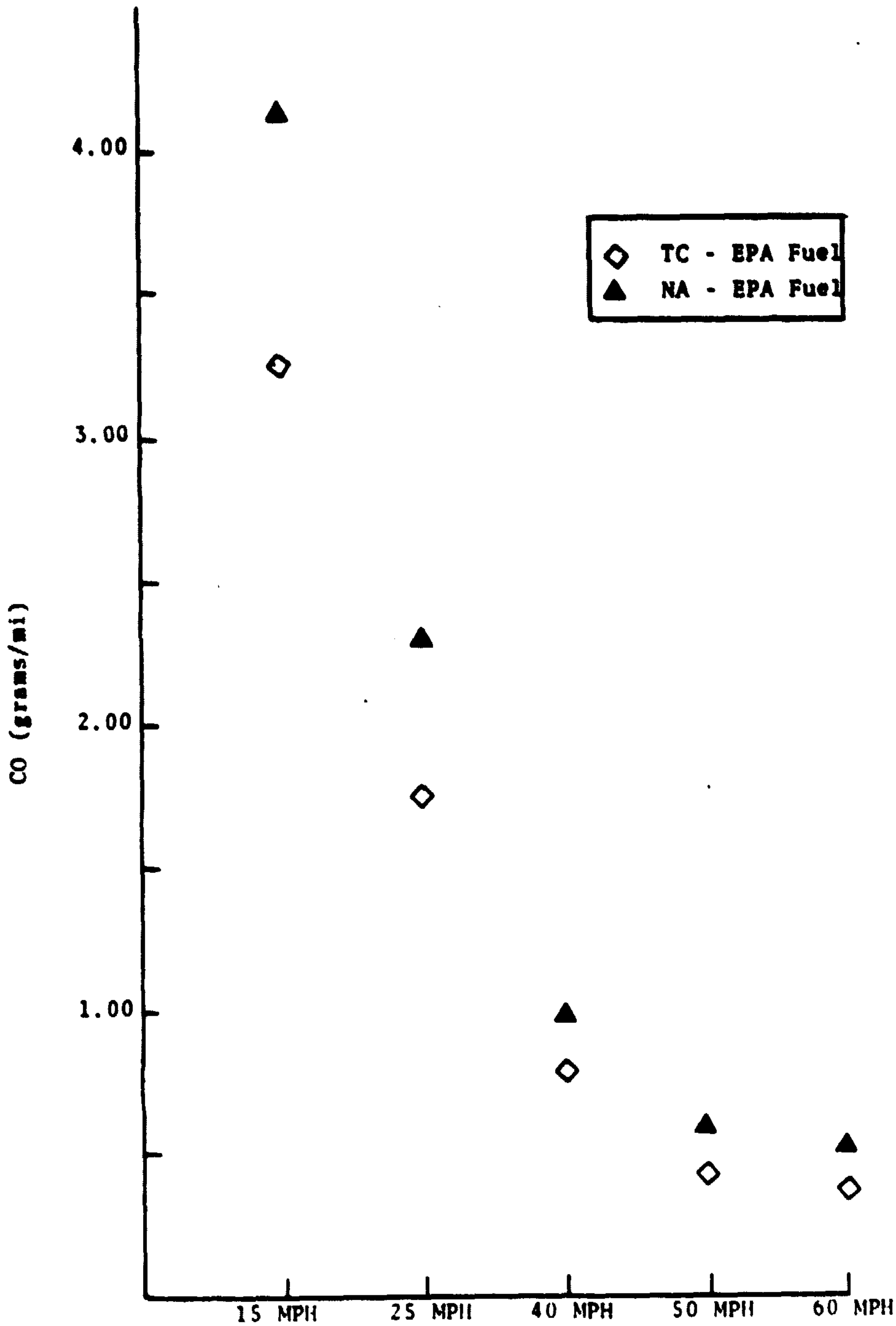

FIGURE 10. FIAT PROTOTYPES: TURBOCHARGED (TC) AND NATURALLY ASPIRATED (NA) CO EMISSIONS - STEADY STATES

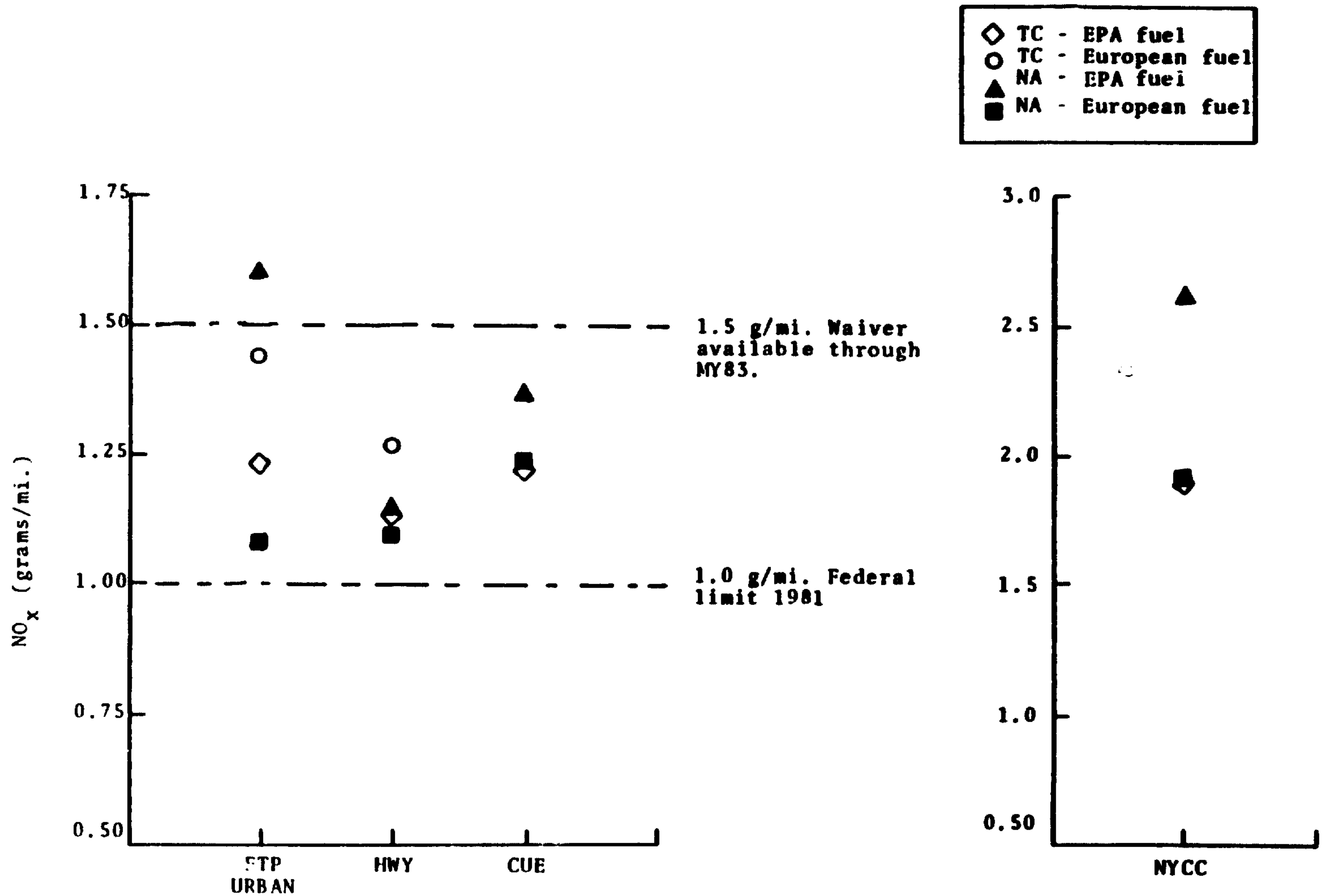

FIGURE 11. FIAT PROTOTYPES: TURBOCHARGED (TC) AND NATURALLY ASPIRATED (NA) 131 NO_x EMISSIONS - CYCLIC TESTS

production. For the turbocharged vehicle the injection timing was retarded which would tend to decrease NO_x levels. Tested with both fuels over the FTP Urban Cycle, the vehicle's NO_x levels fell below the 1.5 g/mi Federal emission limit: 1.23 g/mi for the EPA fuel and 1.43 g/mi for the European fuel. Over the Highway Cycle, the CUE Cycle, the NYCC and the six steady states, the NO_x levels from the turbocharged vehicle run on EPA fuel matched or fell below the naturally aspirated vehicle's NO_x emission levels (Figure 12).

Particulates

Particulate levels were substantially reduced in the turbocharged vehicle; the average reduction over the 6 test points was 30%. All test points showed consistent results except for the NYCC, which showed an increase of 37% (Figures 13 & 14). Fiat in their testing also found particulate reductions of up to 40%.[8]

As discussed in the FIAT 131 NA report, fuel appeared to affect particulate levels sporadically.

Fuel Economy

Turbocharging appeared to contribute to improved fuel economy at low steady-state speeds. (Figure 15) At the 15 and 25 mph steady-state test points fuel economy increased 25% and 8% respectively. However, at the 40-mph test point the turbocharged Fiat showed no significant change in fuel economy over the naturally aspirated vehicle, and at the 50-mph and 60-mph test points small decreases in fuel economy appeared evident. It remains difficult to make definitive judgements about the fuel economy merits of turbocharging because of simultaneous design changes, but presumably the application of turbocharging, particularly at low speeds, results in improved fuel economy due to increased thermal efficiency.

Turbocharging did not appear to have a significant impact on fuel economy over the cyclic tests except when the vehicle was also fuel-optimized (Figure 16). The TC Fiat run on European fuel showed fuel economy improvements of approximately 24% over the other three configurations for the FTP Urban Cycle and a 15% Highway Cycle improvement.

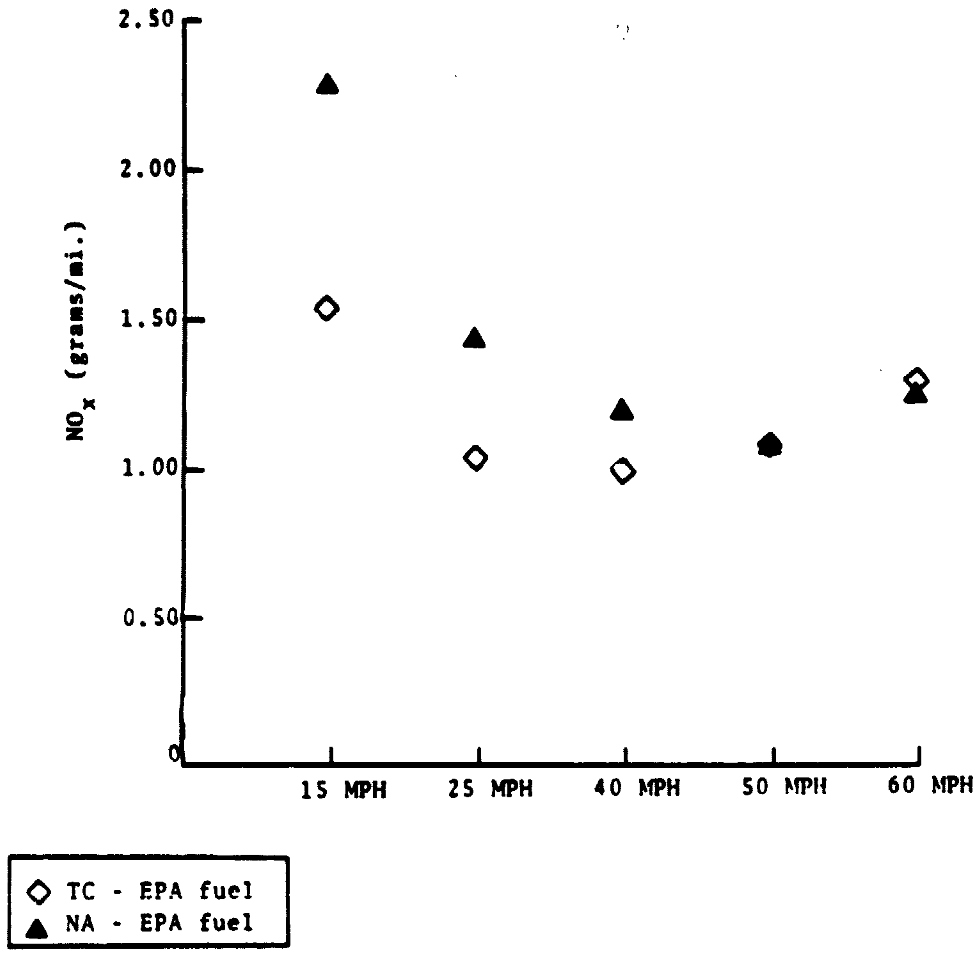

FIGURE 12. FIAT PROTOTYPES: TURBOCHARGED (TC) AND NATURALLY ASPIRATED (NA) NO_x EMISSIONS - STEADY STATES

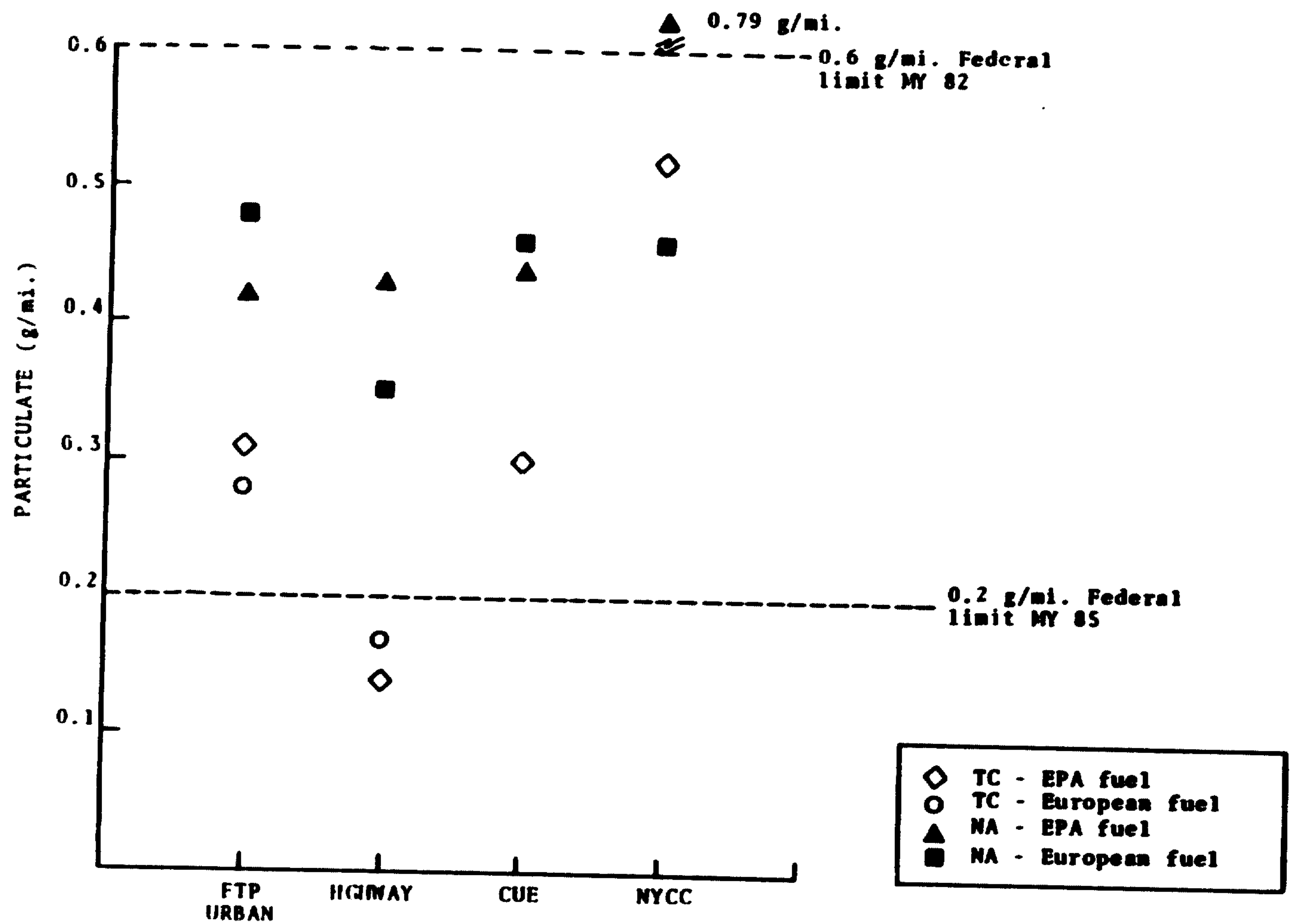

FIGURE 13. FIAT PROTOTYPES: TURBOCHARGED (TC) AND NATURALLY ASPIRATED (NA) PARTICULATE EMISSIONS - CYCLIC TESTS

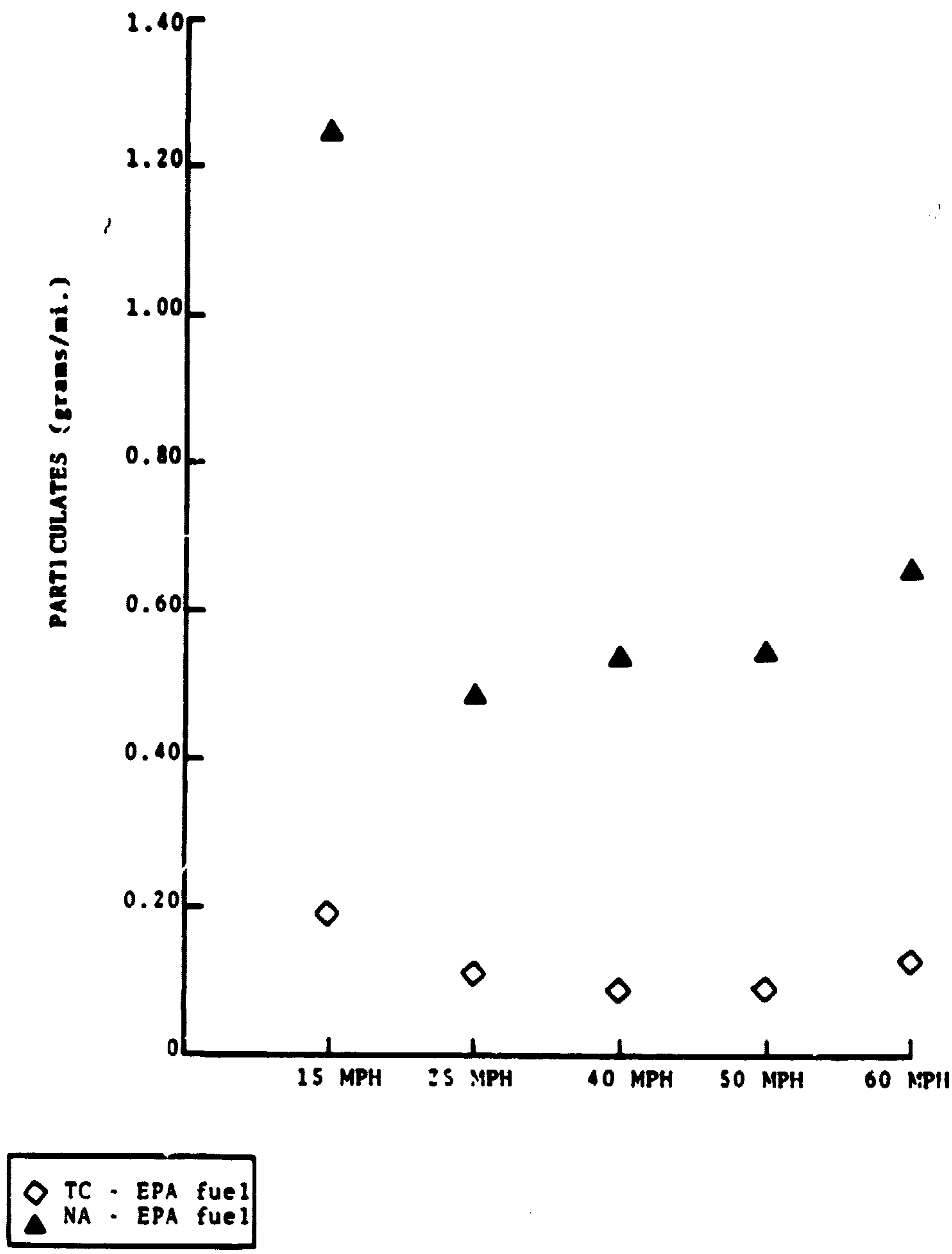

FIGURE 14. FIAT PROTOTYPES: TURBOCHARGED (TC) AND NATURALLY ASPIRATED (NA) PARTICULATE EMISSIONS - STEADY STATES

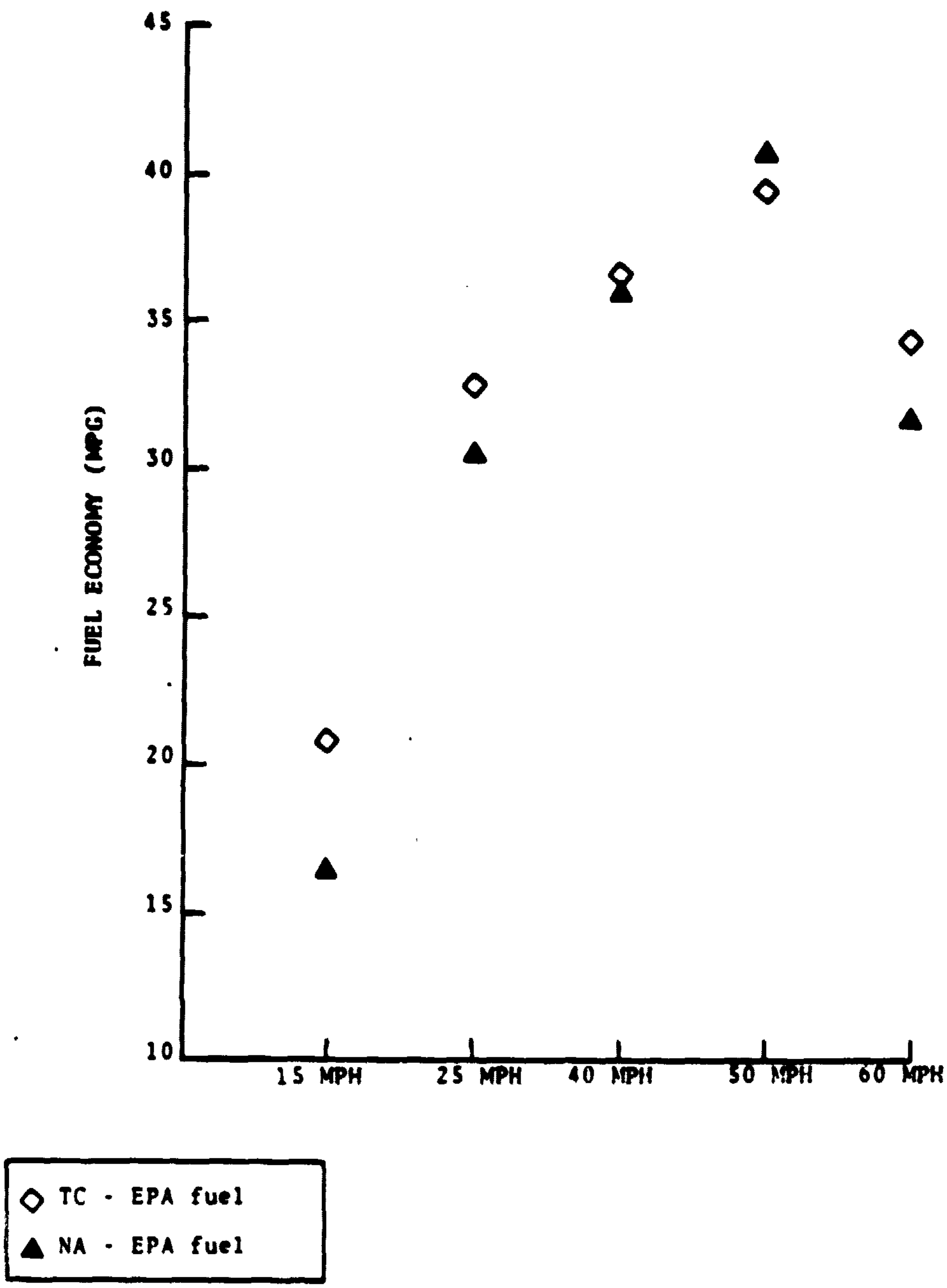

FIGURE 15. FIAT PROTOTYPES: TURBOCHARGED (TC) AND NATURALLY ASPIRATED (NA) FUEL ECONOMY - STEADY STATES

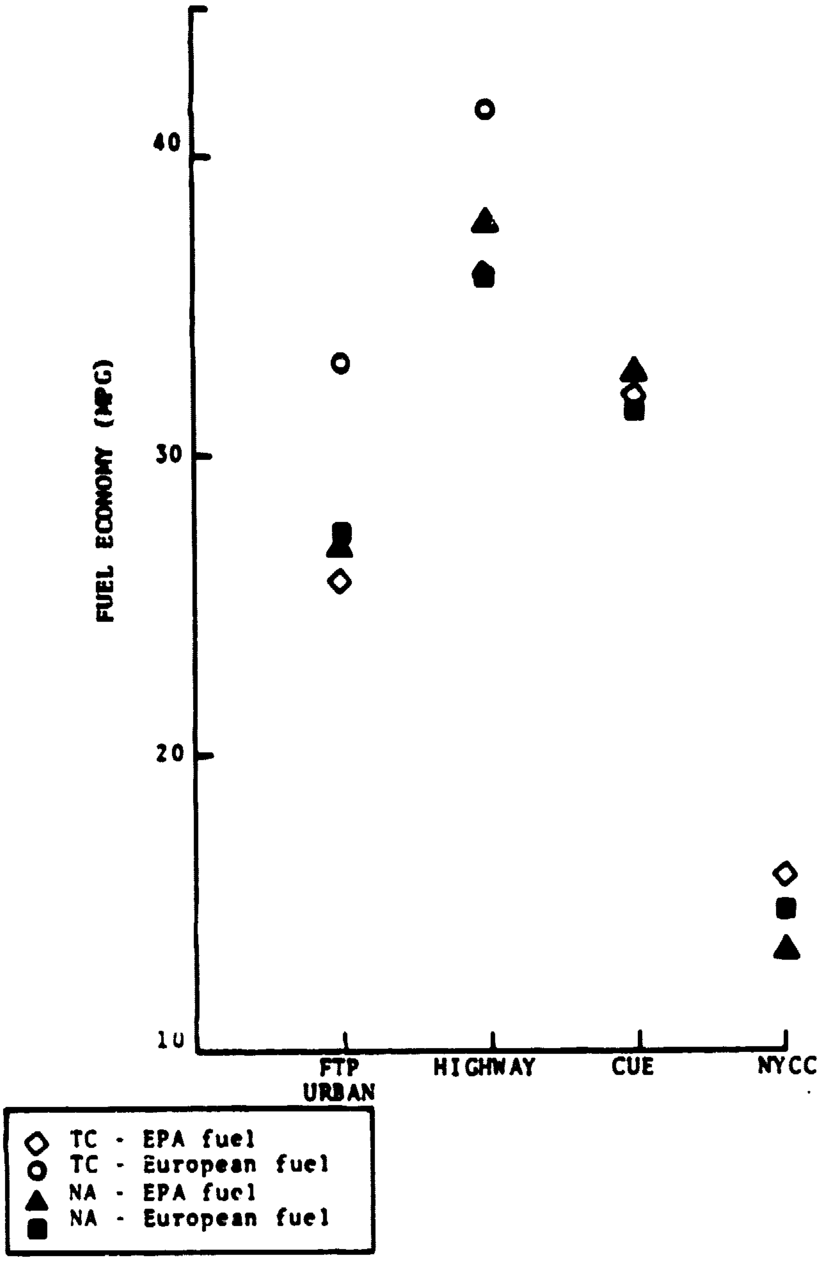

FIGURE 16. FIAT PROTOTYPES: TURBOCHARGED (TC) AND NATURALLY ASPIRATED (NA) <u>FUEL ECONOMY</u> - CYCLIC TESTS

5. CONCLUSIONS

Both the turbocharged and naturally aspirated versions of the Fiat 131 vehicles were tested under a variety of conditions. Based on test results, the following observation was made: turbocharging accompanied by complementary modifications (drive train/engine match, retarded timing, injection component changes) results in small but not unsubstantial improvements in regulated emissions, fuel economy, and performance.

The benefits are:

- o HC and CO reductions, at least 8% and 20-30% respectively.
- o NO_x reductions attributable to the timing and drive train/engine match changes (increased NO_x levels were also noted).
- o Particulate improvements, up to 30%.
- o Minor fuel economy improvements.
- o Improved performance.

In regard to the implementation of turbocharging on diesel passenger vehicles, a few additional points should be considered:

(a) Turbocharging imposes high mechanical loads on certain engine components (the crank shaft, bearings, connecting rods). In the case of automotive diesel engines, turbocharging may require the strengthening of these components if durability and maintenance schedules are to be maintained,

(b) Turbocharging would generally increase the cost of a passenger vehicle \$330 to \$1000 according to industry estimates.[9] However, in some instances, this increased cost may be offset by using a smaller displacement turbocharged engine that would provide equivalent vehicle performance.

(c) The beneficial effect of turbocharging, on particulate emissions, as well as on other, regulated emissions and fuel economy is widely debated.[10,11] This debate is attributed, in part, to the varied response of different engines to turbocharging and the difficulty of separating the effects of turbocharging from the effects of other modifications. These modifications may include fuel system and combustion chamber redesign, increased engine cooling and different engine/drive-train matching.

According to this test series, diesel vehicle turbocharging accompanied by complementary modifications appears to be a viable emissions control technology and should be further examined.

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1. S.S. Quayle, M.M. Davis, and R.A. Walter, "Fuel Economy and Exhaust Emissions Characteristics of Diesel Vehicles: Test Results of a Prototype Fiat 131 NA 2.4 liter Automobile," Report No. DOE/NASA/2817-1, hereafter cited as Fiat 131 NA report.

2. Giorgio M. Cornetti and Cesare Bassoli, "Fiat Diesel Engines Data Base" (Fiat Research Center S.P.A. Tarino Italy, December, 1979, Report No. DOT-TSC-1424.

3. Part 86, "Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines: Certification and Test Procedures" Code of Federal Regulations Protection of the Environment, revised as of July 1, 1980, hereafter cited as Code.

4. Fiat 131 NA report. (See #1 above)

5. Code. (See #3 above)

6. A.D. Tuteja and D.W. Clark, "Comparative Performance and Emission Characteristics of Petroleum, Oil Shale, and Tar Sands Derived Diesel Fuels." SAE 800331.

7. Ibid.

8. C. Bassoli et al., "Exhaust Emission from a European Light Duty Turbocharged Diesel," SAE 790316.

9. "Light-Duty Diesel Engine Development Status and Engine Needs," U.S. Department of Energy, Assistant Secretary for Conservation and Solar Energy, Office of Transportation Programs (August, 1980), p. 3-38.

10. Ibid p. 3-37.

11. "Summary and Analysis of Comments on the Notice of Proposed Rulemaking for Control of Light-Duty Diesel Particulat Emissions form 1981 and later MY Vehicles." U.S. Environmental Protection Agency, Office of Air, Noise and Radiation, Office of Mobile Source Air Pollution Control, (October, 1979).

APPENDIX A

TABLE A-1
LARGE VOLUME PARTICULATE SAMPLES

	NET MASS (grams)	
CYCLE	EUROPEAN FUEL	EPA FUEL
FTP Urban		
Bags 1 and 2	1.81	1.12
Bags 3 and 4	0.62	0.43
Bags 1, 2, and 3	-	0.30
HFET (Highway)	2.69	1.77
NYCC	-	0.61
CUE	-	1.41

TABLE A-2
TEST DATA, MEANS AND STANDARD DEVIATIONS -
FIAT 131 TURBOCHARGED DIESEL - EPA FUEL

CYCLE		GASEOUS EMISSIONS HC g/mi	CO g/mi	NO_x g/mi	PARTICULATE g/mi	FUEL ECONOMY mpg
FTP Urban Bag 1	n	7	7	7	3	7
	$\bar{x}$	0.48	1.81	1.24	0.34	23.8
	s	0.13	0.25	0.10	-	1.27
	2s	0.26	0.50	0.20	-	2.53
Bag 2	n	7	7	7	3	7
	$\bar{x}$	0.36	1.47	1.29	0.31	25.8
	s	0.07	0.15	0.10	-	0.85
	2s	0.14	0.30	0.20	-	1.70
Bag 3	n	8	8	8	3	8
	$\bar{x}$	0.23	1.11	1.19	0.28	27.7
	s	0.04	0.07	0.09	-	0.56
	2s	0.08	0.14	0.18	-	1.13
COMPOSITE	n	5	5	5	3	5
	$\bar{x}$	0.30	1.38	1.23	0.31	26.2
	s	0.50	0.12	0.10	-	0.70
	2s	0.10	0.24	0.20	-	1.4

TABLE A-3
TEST DATA, MEANS AND STANDARD DEVIATIONS -
FIAT 131 TURBOCHARGED DIESEL - EPA FUEL

CYCLE		HC g/mi	CO g/mi	NO_x g/mi	PARTICULATE g/mi	FUEL ECONOMY mpg
HIGHWAY	n	5	5	5	5	5
	$\bar{x}$	0.10	0.48	1.13	0.14	35.9
	s	0.02	0.02	0.05	0.03	0.70
	2s	0.04	0.04	0.10	0.06	1.40
CONGESTED URBAN EXPRESSWAY (Sulfate)	n	4	4	4	4	4
	$\bar{x}$	0.15	0.67	1.22	0.30	32.0
	s	-	-	-	-	-
	2s	-	-	-	-	-
NYCC	n	3	3	3	2	3
	$\bar{x}$	0.82	3.14	1.88	0.52	15.9
	s	-	-	-	-	-
	2s	-	-	-	-	-
STEADY STATE 15mph/ 2nd gear	n	6	6	6	6	6
	$\bar{x}$	0.50	3.25	1.54	0.19	20.8
	s	0.06	0.36	0.08	0.50	0.49
	2s	0.13	0.72	0.15	0.10	0.98

TABLE A-4
TEST DATA MEANS AND STANDARD DEVIATIONS -
FIAT 131 TURBOCHARGED DIESEL - EPA FUEL

GASEOUS EMISSIONS

CYCLE		HC g/mi	CO g/mi	NO_x g/mi	PARTICULATE g/mi	FUEL ECONOMY mpg
STEADY STATE 25 mph/ 3rd gear	n	6	6	6	5	6
	$\bar{x}$	0.29	1.74	1.03	0.11	32.9
	s	0.02	0.09	0.05	0.02	0.70
	2s	0.04	0.18	0.11	0.03	1.4
STEADY STATE 40mph/ 4th gear	n	6	6	6	6	6
	$\bar{x}$	0.15	0.77	0.99	0.09	36.6
	s	0.03	0.06	0.11	0.01	1.02
	2s	0.06	0.11	0.22	0.02	2.04
STEADY STATE 50mph/ 5th gear	n	6	6	6	6	6
	$\bar{x}$	0.09	0.41	1.07	0.09	39.5
	s	0.03	0.01	0.03	0.02	0.58
	2s	0.06	0.02	0.06	0.05	1.16
STEADY STATE 60mph/ 5th gear	n	6	6	6	6	6
	$\bar{x}$	0.08	0.36	1.28	0.13	34.5
	s	0.01	0.01	0.06	0.01	0.32
	2s	0.02	0.02	0.12	0.02	0.64

TABLE A-5
TEST DATA, MEANS AND STANDARD DEVIATIONS -
FIAT 131 TURBOCHARGED DIESEL - EUROPEAN FUEL

		GASEOUS EMISSIONS				
		HC	CO	NO_x	PARTICULATE	FUEL ECONOMY
CYCLE		g/mi	g/mi	g/mi	g/mi	mpg
FTP Urban Bag 1	n	7	7	7	4	7
	$\bar{x}$	0.36	1.53	1.47	0.51	30.6
	s	0.07	0.11	0.04	-	1.30
	2s	0.15	0.22	0.08	-	2.61
Bag 2	n	7	7	7	4	7
	$\bar{x}$	0.27	1.17	1.49	0.27	31.9
	s	0.06	0.11	0.03	-	1.23
	2s	0.12	0.22	0.06	-	2.46
Bag 3	n	6	6	6	3	7
	$\bar{x}$	0.16	0.86	1.34	0.25	35.7
	s	0.04	0.08	0.07	-	1.95
	2s	0.07	0.15	0.13	-	3.90
COMPOSITE	n	6	6	6	6	6
	$\bar{x}$	0.25	1.14	1.43	0.28	33.2
	s	0.05	0.08	0.03	0.07	1.25
	2s	0.10	0.17	0.06	0.15	2.50

TABLE A-6
TEST DATA, MEANS AND STANDARD DEVIATIONS -
FIAT 131 TURBOCHARGED DIESEL - EUROPEAN FUEL

		GASEOUS EMISSIONS				
		HC	CO	NO_x	PARTICULATE	FUEL ECONOMY
CYCLE		g/mi	g/mi	g/mi	g/mi	mpg
HIGHWAY	n	15	15	15	13*	15
	$\bar{x}$	0.07	0.45	1.27	0.17	41.8
	s	0.01	0.02	0.05	0.04	2.68
	2s	0.02	0.06	0.10	0.07	5.35

*Contains combined average runs

TABLE A-7
TEST DATA, FIAT 131 TC DIESEL - EPA FUEL

CYCLE	EMISSIONS HC g/mi	CO g/mi	NO_x g/mi	PARTICULATE g/mi	FUEL ECONOMY MPG	DATE/COMMENTS
FTP Bag 1	0.40	1.67	1.21	-	23.7	80-80
	0.24	1.45	1.32	0.27	23.7	-84
	0.47	1.67	1.08	0.41	24.4	-85
	0.51	1.74	1.16	0.34	26.0	-89
	0.60	1.99	1.25	-	23.3	-96
	0.59	2.21	1.36	-	21.8	-97
	0.56	1.91	1.32	-	23.4	-100
FTP Bag 2	0.39	1.34	1.38	-	25.4	-80
	0.42	1.24	1.32	0.38	26.2	-84
	0.23	1.38	1.13	0.24	26.3	-85
	0.29	1.50	1.15	0.30	27.3	-89
	0.37	1.59	1.31	-	25.7	-96
	0.39	1.63	1.39	-	24.8	-97
	0.43	1.62	1.32	-	25.1	-100
Bag 4	0.31	1.40	1.34	-	26.6	-99
	0.39	1.41	1.25	-	25.7	-98

TABLE A-8
TEST DATA, FIAT 131 TC DIESEL -
EPA FUEL

	EMISSIONS					
	HC	CO	NO_x	PARTICULATE	FUEL ECONOMY	
CYCLE	g/mi	g/mi	g/mi	g/mi	mpg	DATE/COMMENTS
FTP, Bag 3	0.21	1.04	1.32		26.9	80-80
	0.16	1.02	1.31	0.25	27.5	-84
	0.21	1.08	1.08	0.25	28.9	-85
	0.21	1.10	1.17	0.33	27.8	-89
	0.23	1.11	1.11	-	27.7	-96
	0.26	1.25	1.17	-	27.4	-98
	0.27	1.18	1.18	-	27.7	-99(1)
	0.26	1.08	1.19	-	27.6	-99(2)
FTP COMPOSITE	0.26	1.33	1.33	-	25.5	-80
	0.26	1.22	1.32	0.32	26.0	-84
	0.28	1.36	1.11	0.28	26.6	-85
	0.31	1.44	1.16	0.32	27.2	-89
	0.38	1.54	1.24	-	25.7	-96

TABLE A-9
TEST DATA, FIAT 131 TC DIESEL-
EPA FUEL

	EMISSIONS					
	HC	CO	NO_x	PARTICULATE	FUEL ECONOMY	
CYCLE	g/mi	g/mi	g/mi	g/mi	mpg	DATE/COMMENTS
HIGHWAY	0.09	0.45	1.46		33.2	80-81**
	0.07	0.48	1.08	0.12	35.4	-86
	0.09	0.49	1.17	0.15	35.1	-90
	0.20	0.57	1.28	0.04*	35.6	80-94**
	0.14	0.48	1.27	0.04*	34.1	-94**
	0.15	0.53	1.27	0.04*	33.9	-94**
	0.09	0.45	1.08	0.13	36.9	-116
	0.10	0.48	1.19	0.11	36.1	-117
	0.13	0.49	1.11	0.18	36.0	-117
CUE	0.11	0.59	1.13	0.41	30.6	-83
	0.11	0.64	1.14	0.16	33.7	-88
	0.16	0.63	0.98	0.18	31.3	-91
	0.20	0.80	1.64	0.43	32.5	-95
NYCC	0.98	3.19	2.05	0.88	15.5	-82
	0.66	3.14	1.84	0.59	16.0	-87
	0.81	3.09	1.76	0.45	16.2	-92

*20" x 20" filter: average value.
**Not included in mean.

TABLE A-10

TEST DATA, FIAT 131 TC DIESEL-
EPA FUEL

	EMISSIONS					
	HC	CO	NO_x	PARTICULATE	FUEL ECONOMY	
CYCLE	g/mi	g/mi	g/mi	g/mi	mpg	DATA/COMMENTS
15 mph, 2nd gear	0.45	3.88	1.44	0.20	20.9	80-102
	0.61	3.37	1.48	0.28	21.8	-102
	0.43	2.89	1.66	0.13	20.5	-108
	0.49	3.00	1.58	0.15	20.7	-108
	0.53	3.31	1.56	0.19	20.5	-111
	0.50	3.07	1.54	0.19	20.7	-111
25 mph, 3rd gear	0.29	1.71	1.08		32.6	-101
	0.31	1.61	1.05	0.12	34.2	-101
	0.31	1.85	1.06	0.10	32.5	-103
	0.31	1.74	1.05	0.09	32.5	-103
	0.27	1.83	0.94	0.10	33.0	-112
	0.27	1.72	0.98	0.13	33.0	-112
40 mph, 4th gear	0.15	0.71	1.13	0.10	35.1	-106
	0.16	0.69	1.10	0.10	36.8	-106
	0.13	0.77	1.00	0.08	37.9	-113
	0.18	0.86	0.95	0.09	35.8	-113
	0.15	0.80	0.88	0.07	37.2	-115
	0.17	0.83	0.86	0.08	37.1	-115

TABLE A-11
TEST DATA, FIAT 131 TC DIESEL-
EPA Fuel

	EMISSIONS					
	HC	CO	NO_x	PARTICULATE	FUEL ECONOMY	
CYCLE	g/mi	g/mi	g/mi	g/mi	mpg	DATE/COMMENTS
50 mph, 5th gear	0.15	0.42	1.07	0.13	39.7	80-104
	0.08	0.40	1.07	0.06	39.5	-104
	0.08	0.40	1.12	0.07	40.5	-105
	0.08	0.42	1.08	0.09	39.4	-105
	0.07	0.42	1.02	0.08	39.4	-110
	0.08	0.41	1.07	0.09	39.7	-110
60 mph, 5th gear	0.08	0.36	1.20	0.13	34.4	-107
	0.09	0.36	1.32	0.14	35.0	-107
	0.07	0.34	1.36	0.12	34.3	-109
	0.07	0.36	1.24	0.13	34.1	-109
	0.08	0.36	1.23	0.14	34.7	-114
	0.09	0.35	1.31	0.14	34.4	-114

TABLE A-12
TEST DATA, FIAT 131 TC DIESEL - EUROPEAN FUEL

	EMISSIONS					
	HC	CO	NO_x	PARTICULATE	FUEL ECONOMY	
CYCLE	g/mi	g/mi	gm/i	g/mi	mpg	DATE/COMMENTS
FTP Bag 1	0.23	1.44	1.40	0.45	32.2	80-55
	0.36	1.57	1.44	0.52	29.3	80-58
	0.31	1.35	1.46	0.42	28.6	80-60
	0.38	1.54	1.47	0.66	31.5	80-63
	0.47	1.59	1.51	-	30.2	80-66
	0.37	1.52	1.51	-	31.6	80-71
	0.40	1.70	1.51	-	30.6	80-75
Bag 2	0.18	1.07	1.46	0.30	34.2	80-55
	0.33	1.07	1.47	0.20	30.7	80-58
	0.21	1.03	1.47	0.25	30.6	80-60
	0.26	1.21	1.43	0.32	32.4	80-63
	0.35	1.22	1.52	-	31.6	80-66
	0.29	1.25	1.47	-	32.4	80-71
	0.30	1.32	1.51	-	31.6	80-75

TABLE A-13
TEST DATA, FIAT 131 TC DIESEL - EUROPEAN FUEL

	EMISSIONS					
	HC	CO	NO_x	PARTICULATE	FUEL ECONOMY	
CYCLE	g/mi	g/mi	g/mi	g/mi	mpg	DATE/COMMENTS
Bag 3	0.11	0.77	1.24	0.27	39.1	80-55
	0.15	0.76	1.33	0.21	34.3	80-60
	0.14	0.90	1.30	0.28	35.9	80-63
	0.22	0.93	1.39	-	34.2	80-66
	0.16	0.90	1.43	-	34.2	80-72
	0.18	0.91	1.32	-	36.7	80-75
Bag 4	0.29	1.06	1.48	-	33.1	80-66
	0.19	1.08	1.46	-	34.0	80-72
	0.25	1.18	1.36	-	34.3	80-75
COMPOSITE	0.17	1.06	1.39	0.33	35.0	80-55
	0.22	1.02	1.43	0.27	31.2	80-60
	0.25	1.19	1.41	0.38	33.2	80-63
	0.32	1.17	1.47	0.17	33.6	80-66
	0.24	1.16	1.46	0.24	32.7	80-71/72
	0.27	1.24	1.41	0.26	33.6	80-75/76

TABLE A-14
TEST DATA, FIAT 131 TC DIESEL - EUROPEAN FUEL

	EMISSIONS					
	HC	CO	NO_x	PARTICULATE	FUEL ECONOMY	
CYCLE	g/mi	g/mi	g/mi	g/mi	mpg	DATE/COMMENTS
Highway (W/Use of 5th gear)	0.09	0.48	1.21	0.24	45.5	4/10 80-53
	0.07	0.45	1.18	0.16	47.3	4/10 80-54
	0.06	0.46	1.28	0.19	39.8	4/11 80-56
	0.05	0.43	1.28	0.18	41.8	4/11 80-57
	0.08	0.47	1.30	0.21	41.2	4/17 80-61
	0.07	0.42	1.29	0.15	43.5	4/17 80-62
	0.08	0.42	1.28	0.22	39.5	4/18 80-64
	0.06	0.41	1.22	0.16	46.1	4/18 80-65
	0.07	0.47	1.32	0.13*	39.5	4/21 80-68
	0.08	0.44	1.28	0.13*	42.4	4/21 80-69
	0.07	0.44	1.30	0.13*	40.6	4/21 80-70
	0.08	0.47	1.36	-	38.2	4/22 80-73
	0.07	0.44	1.19	-	39.9	4/22 80-79
	0.08	0.47	1.30	0.17*	40.9	4/23 80-77
	0.06	0.49	1.28	0.17*	40.9	4/23 80-78

*AVERAGE OF COMBINED RUNS

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